Material Characterization

Material Summary

Material List (source CASA ATLAS CYLINDER CONTROL REPORT N° DE97/I-002/IE1)

Item	*Commercial ID*	*Chem/Type*	*Procurement*	*Processing*	*Use & location*
1	Carbon Honeycomb UCF-51-3/8-2.0	XN50 Fabric / RS3 Resin	YLA Cellular Products (USA)		Cylinder Core h=5.6mm
2	XN50/RS3 29%	Carbon Fiber XN50 + Cyanoester resin RS3 prepreg Tape	YLA Incorporated (USA)	180° Autoclave cure	Cylinder skins (0°,60°-60°)
3	1515/T300	Carbon Fiber + Cyanoester resin prepreg Tape	Bryte Technologies Inc. USA	125° Autoclave cure	Cleats (0°,45°)
4	EX 1510	cyanate ester resin	Bryte Technologies Inc. USA	RTM processing	Flanges
5	5 PYS 50a - 50/5617	Carbon Fiber Spiral Cloth	Nippon Graphite Fabric. (Japan)	RTM processing	Flanges (7 plies)

Available Tests

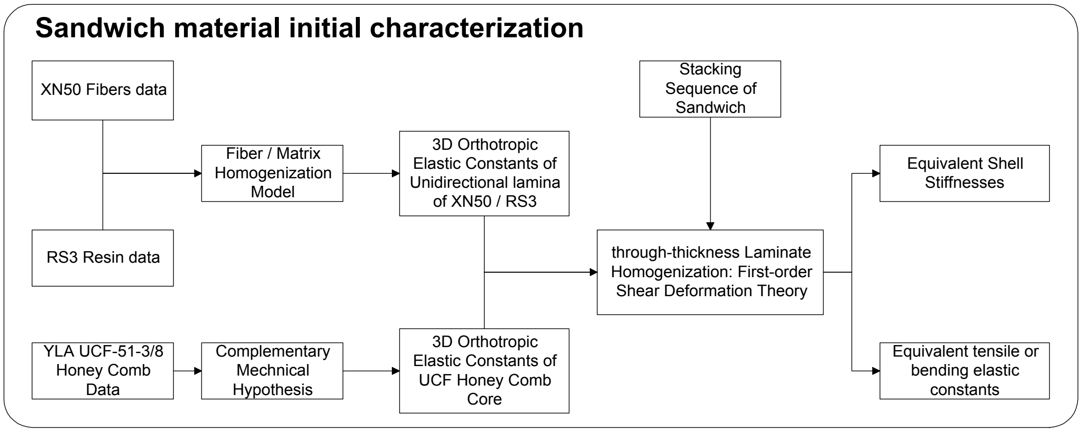
- Shipment Tests On Fibers, from CASA Control Report DE97/I-002/IE1
- Modulus Tests On Samples of Flat Laminate of XN50/RS3 (0 +60 -60 -60 +60 0) 1,75mm:ASTM 3039 at 0° and 90°, from CASA Control Report DE97/I-002/IE1
- Strength Tests on samples of Flat Sandwich (0 / +60 / -60 / RS4A / Carbon-Core / Rs4a / -60 / +60 / 0) 5.8mm , Flexural Strength Test, ASTM C 393 at 0° and Flatwise Tensile ASTM C297. source CASA Control Report DE97/I-002/IE1
- Tests on Barrel Specimen, source CASA Control Report DE97/I-002/IE1

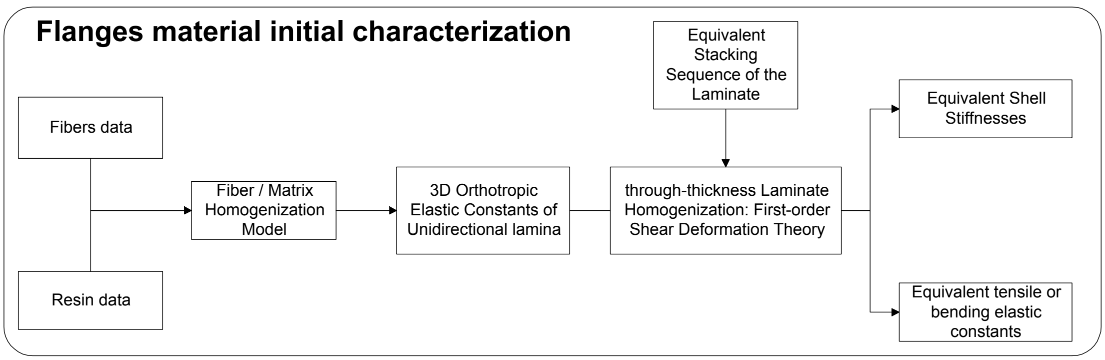
Available Material Data

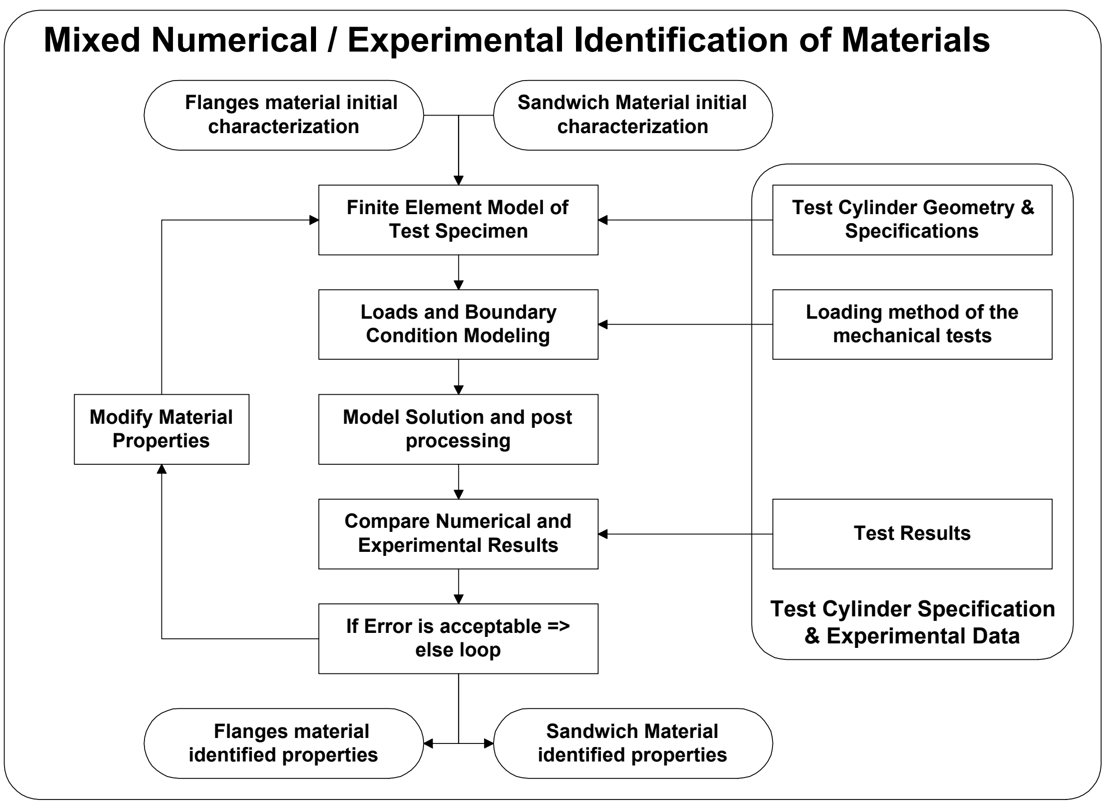
- XN50/RS3 Prepregs, Source YLA Conformance Certificate, YLA CERTIFICATE N°3177
- RS3 Resin Properties, source YLA INC Web Site: http://www.ylainc.com/products/data_sheets/rs_3.htm
- XN50A 20N fiber properties, Nippon Graphite Fiber Corp
- Honey Comb YLA UCF-51-3-8-2.0 properties, source YLA Web Site, http://www.ylacp.com/prop.html, last update 6.6.2000.

Material Characterization Method

As the material properties provided by the manufacturers are not complete enough for a 3D Finite Element simulation of the SCT Barrels, we have had to supplement the material data. The method that was used in this study is described below:


Sandwich material initial characterization
XN50 Fibers data
RS3 Resin data
Fiber / Matrix Homogenization Model
3D Orthotropic Elastic Constants of Unidirectional lamina of XN50 / RS3
Stacking Sequence of Sandwich
through-thickness Laminate Homogenization: First-order Shear Deformation Theory
Equivalent Shell Stiffnesses
Equivalent tensile or bending elastic constants
YLA UCF-51-3/8 Honey Comb Data
Complementary Mechnical Hypothesis
3D Orthotropic Elastic Constants of UCF Honey Comb Core


Flanges material initial characterization
Equivalent Stacking Sequence of the Laminate
Fibers data
Resin data
Fiber / Matrix Homogenization Model
3D Orthotropic Elastic Constants of Unidirectional lamina
through-thickness Laminate Homogenization: First-order Shear Deformation Theory
Equivalent Shell Stiffnesses
Equivalent tensile or bending elastic constants


Mixed Numerical / Experimental Identification of Materials
Flanges material initial characterization
Sandwich Material initial characterization
Finite Element Model of Test Specimen
Test Cylinder Geometry & Specifications
Loads and Boundary Condition Modeling
Loading method of the mechanical tests
Modify Material Properties
Model Solution and post processing
Compare Numerical and Experimental Results
Test Results
If Error is acceptable => else loop
Test Cylinder Specification & Experimental Data
Flanges material identified properties
Sandwich Material identified properties

XN50 / RS3 Unidirectional Prepregs

The mechanical/physical properties of the XN50/RS3 prepregs provided by YLA are the following:

Lot N°	Tens Strength	Tens Modulus	Flex Strength	Flex Modulus	InterLam Shear Strength
	MPa	GPa	MPa	GPa	MPa
FB3K863	1687	307	824	238	74

Cured Ply Thickness	Fiber Volume
mm	%
1.8	60

SurfWeight	Resin Content Volume	Volatile Content
76 g/m2	29.50%	0.80%

(source YLA CERTIFICATE N°3177, CASA Control Report, DE97/I-002/IE1)

This mechanical property set is not complete enough for a finite element (3D shell) model of the structure. In order to evaluate the missing properties, we have used fiber/matrix homogenization models. Those semi-empirical models use the Fiber and Resin properties and the fiber volume fraction to predict the equivalent 3D elastic constants of a unidirectional lamina. A lot of different homogenization models can be found in the specialized literature, but only some are usually considered to be reliable in most application. A good comparative study of those models can be found in Bogdanovich, Pastor, Mechanics of Textile and Laminated composites, London: Chapman & Hall, 1996, ref BC: Jd 754 . In this book, it has been showed that the most reliable models are the Abolinsh and Vanyin (or Van Fo Fy) Models.

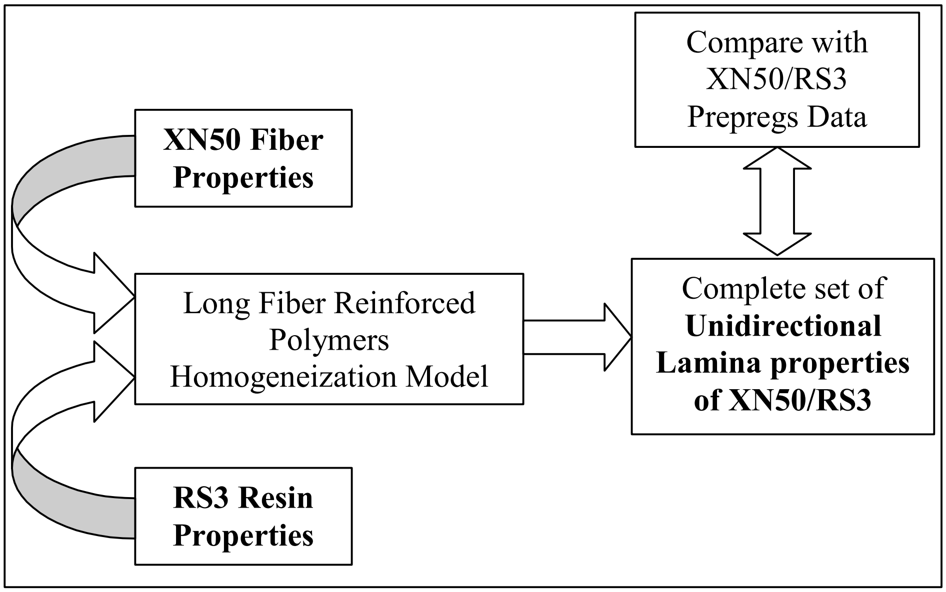


Figure : Fiber / Matrix Homogenization of a XN50/RS3 UD lamina.

In the present study, we have used both of these models to predict the 3D elastic properties of a unidirectional lamina. The retained values are the average of the prediction of both models. The predicted properties can be found in Appendix 2, and the complete set of fiber and resin properties are in Appendix 1. The resulting values have been compared with the tensile modulus from the YLA XN50/RS3 prepreg conformance certificate and we have found that the model is in good agreement with the certified values. The resulting values of the homogenization model are the following:

Variable	Longitudinal Young Modulus	Transverse Young Modulus	Longitudinal Shear Module	Transverse Shear Modulus	Long-Transv Poisson Ratio	Transv-Transv Poisson Ratio
Name	E_cl	E_ct	G_cl	G_ct	Nu_clt	Nu_ctt
Unit	Pa	Pa	Pa	Pa	-	-
Value	3.09E+11	1.89E+10	8.93E+09	8.03E+09	3.69E-01	6.02E-01

UCF-51-3/8 Carbon Honey Comb

Only few mechanical data is available for the UCF-51-3/8 Honey Comb from YLA. The following property table can be found on YLA web site :

HoneyComb YLA UCF-51-3-8-2.0

source YLA WebSite, http://www.ylacp.com/prop.html, last update 6.6.2000

ULTRACORE	Construction	Compressive	Plate Shear

Product Code :				L-Direction		W-Direction	
		Strength	Modulus E3	Strength	Modulus G13	Strength	Modulus G23
material-cell-density		psi	ksi	psi	ksi	psi	ksi
		KPa	MPa	KPa	MPa	KPa	MPa
XN50 / RS3							
UCF-51-3/8-2.0	±45° XN50	205	34	120	60	57	25
		1413	234	827	414	393	172

Where the direction are:

- L or direction 1, along the length of the building ribbon.
- W or direction 2, the expansion direction of the honey comb.
- Direction 3, along the cell axis, normal to the mid plane of the core.

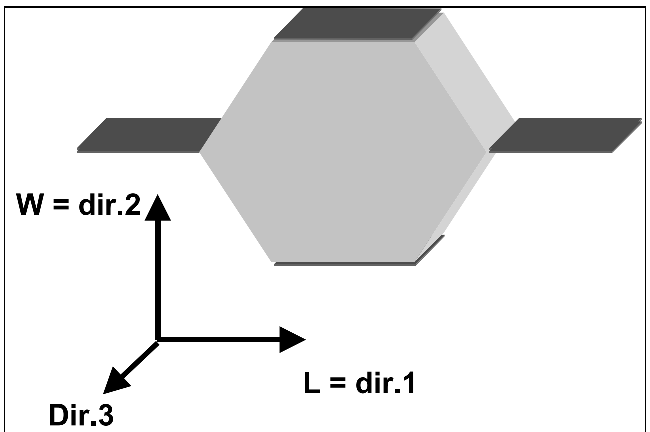


Figure : Honey Comb related coordinate system

In order to model the sandwich material of the cylinders, we need a complete 3D orthotropic characterization of the material. Some physically reasonable hypothesis have been made to predict the three dimensional elastic behavior of the honey comb core :

(1) The Young Moduli E1,E2 are considered to be much smaller than E3, and than the transverse shear moduli in general (G23, G31). So we consider E1 and E2 to be of the order of 1/10 of the E3 modulus.

(2) The in plane shear modulus G12 is considered to be much smaller than the transverse shear moduli (G23, G13). G12 is then considered ton be of the order of 1/100 of 0.5 x (G13 + G23).

(3) The hexagonal cells are considered to be quasi incompressible in the L / W plane (constant surface of cell) . So the in plane Poisson Ratio Nu12 is estimated to be 0.4.

(4) The cells are considered to be quasi invariant in thickness. The Poisson ration Nu23 and Nu 31 are considered to be near 0.1.

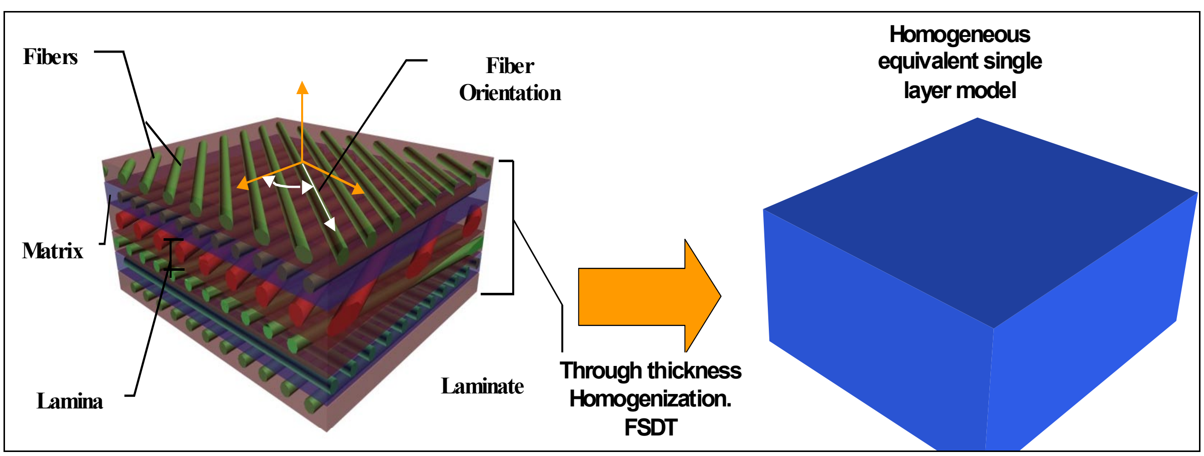
The initial guess of the 3D elastic constants of the UCF honey comb core are then the following:

Property	***E1***	***E2***	***E3***	***G12***	***G13***	***G23***
Unit	Pa	Pa	Pa	Pa	Pa	Pa
Value	2.24E+07	2.24E+07	2.24E+08	2.93E+06	4.14E+08	1.72E+08
Source	(1)	(1)	YLA Data	(2)	YLA Data	YLA Data

Property	***nu12***	***nu23***	***nu31***
Unit	-	-	-
Value	0.4	0.1	0.1
Source	(3)	(4)	(4)

Flanges Material

The flanges are made of a special cyano-ester / carbon composite. The reinforcement of this composite is a spiral cloth of graphite fiber (Nippon Graphite Fabric), which structure make it difficult to model. According to the experience of the manufacturers, this composite can be considered to be equivalent to a quasi – isotropic laminate of XN50 / RS3 (same type of resin, fibers). The initial guess of the flanges material properties have been obtained by the homogenization of a XN50/RS3 (0,45,90,-45)s laminate (thickness = 2mm). The properties used for each layer of laminate are the ones that have been calculated for the XN50/RS3 60%vol unidirectional lamina. The equivalent 3D elastic constants have been derived using a laminate homogenization that is based on First-order Shear Deformation Theory (FSDT). The FSDT approach differs from the Classical Laminated Plate Theory in the sense that FSDT does not neglect the Transverse Shear Effects (Mindlin theory of plates) . The First-order Shear Deformation Theory is usually the fundamental hypothesis of most of the shell finite element model and is considered as an optimum between accuracy and computing cost. The FSDT is based on the hypothesis of a linear displacement field through the thickness of the laminate, but can account for free rotation of the cross sections (transverse shear effects). This theory and its application to through thickness homogenization of laminates can be found in J.N. Reddy *Mechanic of Laminated Composite Plates: Theory and Analysis* CRC Press, 1997.



/

In the FSDT homogenization process, the equivalent shell stiffnesses are deduced: equivalent tensile (A), bending (D), shear (D') and tensile-bending coupling (B) stiffness matrices. From these equivalent stiffnesses, we can deduce the tensile-equivalent orthotropic elastic constants of the laminate. The results of the calculations are shown below and in Appendix 3:

Variable	*Young Modulus E1*	*Young Modulus E2*	*Poisson Ratio Nu12*	*Poisson Ratio Nu21*	*Shear Modulus G12*	*Shear Modulus G23*	*Shear Modulus G31*
Unit	*Pa*	*Pa*	*-*	*-*	*Pa*	*Pa*	*Pa*
Value	1.16E+11	1.16E+11	3.24E-01	3.24E-01	4.40E+10	8.48E+09	8.48E+09

Sandwich material characterization

The cylinder of the SCT are made of a XN50/RS3 sandwich structure, which is mainly composed of YLA UCF-51-3/8-2.0 Honey Comb Core (~5.6mm) and 2 skins of (0°,60°,-60°) XN50/RS3 laminate. Estimation of the 3D elastic properties of the honey comb core and of the unidirectional XN50/RS3 lamina have been made previously. The global 3D mechanical behavior of the sandwich can be derived by using a through-thickness homogenization technique, like the FSDT one that has already been used in the present work. Given the constitutive properties of each layer (lamina) and the stacking sequence of the laminate, we can determine the equivalent shell stiffness matrices of the sandwich. Here is the description of the stacking sequence of the sandwich:

Layer number	**Orientation (°)**	**Thickness (mm)**	**Material Properties**
1	0°	0.065 mm	XN50/RS3 Unidirectional Lamina
2	60°	0.065 mm	XN50/RS3 Unidirectional Lamina
3	-60°	0.065 mm	XN50/RS3 Unidirectional Lamina
4	0°	5.600 mm	UCF-51-3/8-2.0 Honey Comb Core
5	-60°	0.065 mm	XN50/RS3 Unidirectional Lamina
6	60°	0.065 mm	XN50/RS3 Unidirectional Lamina
7	0°	0.065 mm	XN50/RS3 Unidirectional Lamina

This homogenization computations have been done internally by I-Deas v8 FEA software, the principal resulting values are the following:

Material Property	MASS DENSITY	LAMINATE THICKNESS
Unit :	KILOGRAM/METER^3	METER
Value :	3.03E+02	5.99E-03

Material Property MEMBRANE PROPERTIES
Unit : NEWTON/METER

5.09E+07	1.65E+07	0.00E+00
1.65E+07	5.09E+07	0.00E+00
0.00E+00	0.00E+00	1.72E+07

Material Property COUPLED MEMBRANE-BENDING PROPERTIES
Unit : NEWTON

0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00

Material Property BENDING PROPERTIES
Unit : NEWTON METER

4.40E+02	1.35E+02	1.59E+00
1.35E+02	4.18E+02	4.53E+00
1.59E+00	4.53E+00	1.42E+02

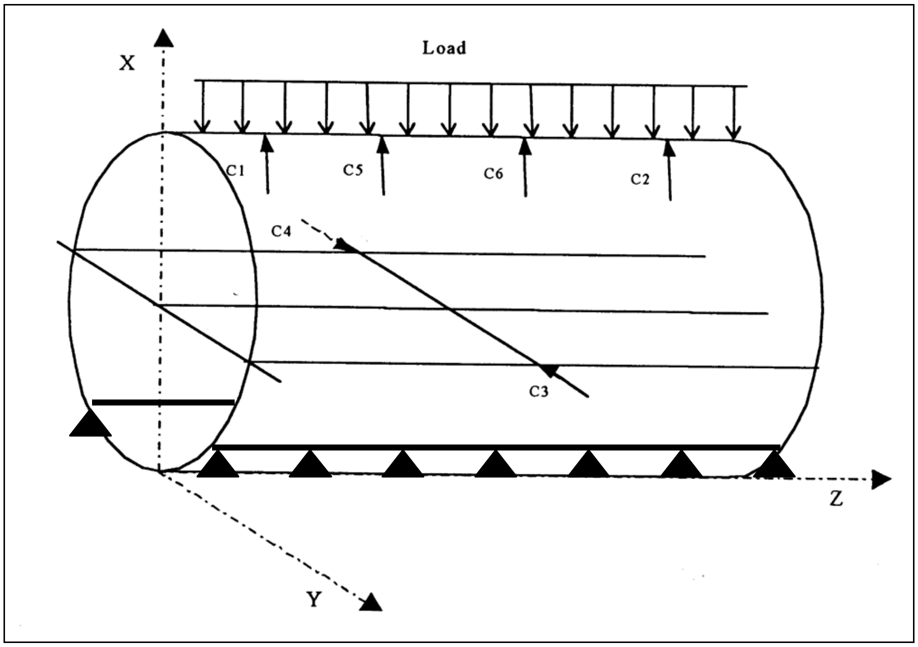
Material Property TRANSVERSE SHEAR PROPERTIES
Unit : NEWTON/METER

2.56E+06	-1.86E+01
-1.86E+01	1.01E+06

Mixed Numerical / Experimental Material Identification.

At this point, all the material constants have been estimated by various homogenization models. Because of the assumptions of perfect bonding used in these models, the values that they predict can be considered as ideal ones. In order to guarantee the reliability of the final FE model, these values have to be compared with experimental results. The next stage of the material characterization process is then to identify the real material properties by comparing the experimental results of the Test Cylinder to the results of the corresponding FE simulation.

The test cylinder and the mechanical loading experiment description can be found in CASA Control Report DE97/I-002/IE1. The cylinder has been tested with and without flanges. The cylinder is supported along 2 straight linear support, oriented along the cylinder axis and spaced of 356 mm. A constant linear load is applied through a rigid bar on the top of the cylinder. The displacements are measured in 6 points (C1 to C6).



A FE model of the test cylinder as been made, using the initial guess of material constants described above. The corresponding loads and boundary condition have also been modeled. The FE analysis has been computed with I-Deas Master v8 simulation module. The elements used to model the test cylinder are Serendipian quadratic FSDT laminated shells (Mindlin theory). The material preoperties have been identified by iteration and progressive modification. At each step, the error between numerical and experimental results is evaluated for each measurement point. A simple sensitivity analysis gives us the most influencing parameters , which are then corrected and the process goes on until the error is acceptable. In this case, the most sensitive parameter are the bending stiffnesses of the laminate and the tensile properties of the flanges material..

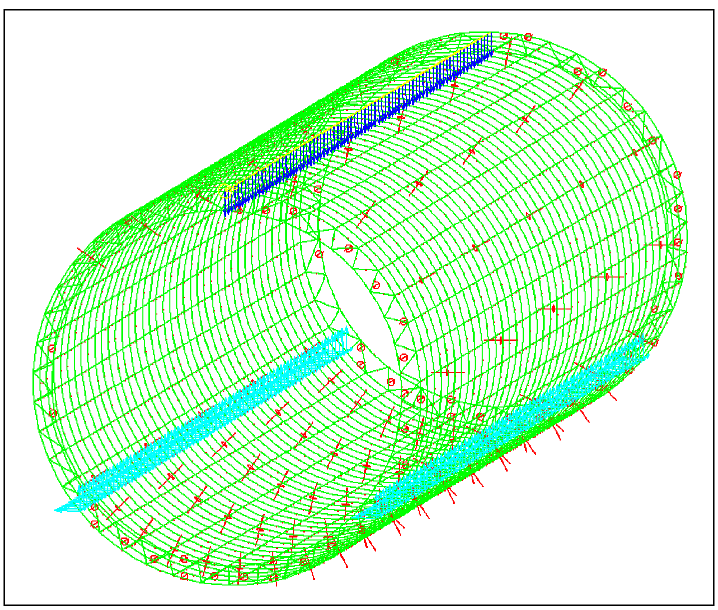


Figure: FE model of the test cylinder, with flanges, loads and supports.

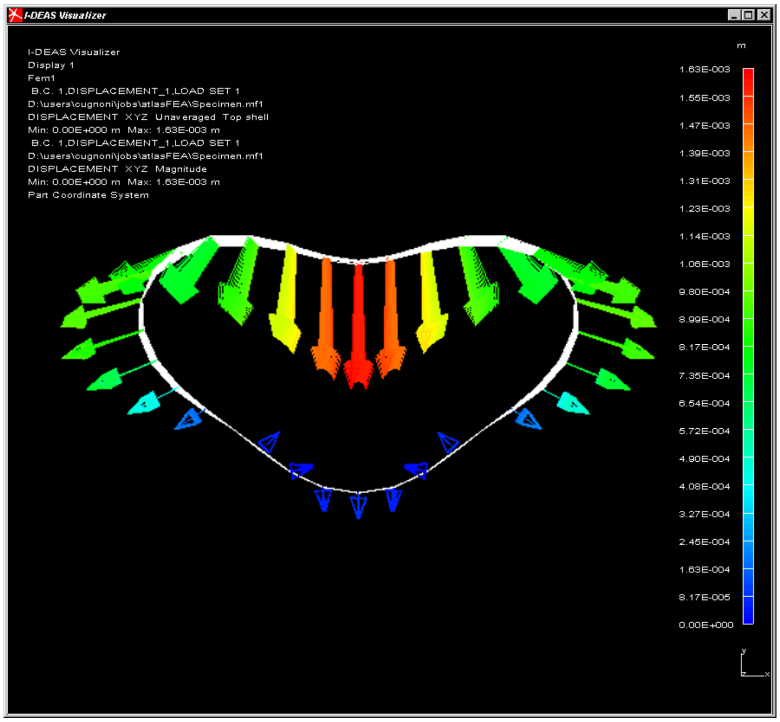


Figure: FE model of the test cylinder, without flanges, showing XY displacement field, min=0m, max=1.63mm.

- ***Sandwich Laminate:*** (laminated shell model)

Thickness	*0.00599*	*m*
Density	303.2521	kg/m3

Membrane Properties			
Aij	*1 (1)*	*2 (2)*	*3 (6)*
1 (1)	6.60E+07	2.43E+07	0.00E+00
2 (2)	2.43E+07	6.60E+07	0.00E+00
3 (6)	0.00E+00	0.00E+00	2.15E+07

coupling tensile/bending			
Bij	*1 (1)*	*2 (2)*	*3 (6)*
1 (1)	0.00E+00	0.00E+00	0.00E+00
2 (2)	0.00E+00	0.00E+00	0.00E+00
3 (6)	0.00E+00	0.00E+00	0.00E+00

Bending properties			
Dij	*1 (1)*	*2 (2)*	*3 (6)*
1 (1)	1.31E+02	4.84E+01	0.00E+00
2 (2)	4.84E+01	1.31E+02	0.00E+00
3 (6)	0.00E+00	0.00E+00	4.28E+01

Transverse shear properties		
Dij	*1 (4)*	*2 (5)*
1 (4)	1.52E+07	0.00E+00
2 (5)	0.00E+00	3.85E+06

Displacements for cylinder without flanges for final material properties

POINT	*C1*	*C2*	*C3*	*C4*
Measured Displacement mm	1.48	1.52	0.71	0.91
Calculated Displacement mm	1.58	1.58	0.87	0.88

- ***Flanges Material:*** (orthotropic model)

Property	*E1*	*E2*	*E3*
Unit	*Pa*	*Pa*	*Pa*
Value	3.50E+10	3.50E+10	3.50E+10

Property	*Nu12*	*Nu23*	*Nu13*
Unit	-	-	-
Value	2.90E-01	2.90E-01	2.90E-01

Property	*G12*	*G23*	*G13*
Unit	*Pa*	*Pa*	*Pa*
Value	9.00E+09	5.00E+09	5.00E+09

If we compare the identified values, we can see that the "real" material properties are often much below the estimated ones. Even if the identification of the sandwich material was quite easy to perform, the identification of the flanges material was more difficult, because the sensitivity of the structure to this sub-structure is highly non-linear and varies a lot from one point to another. The experimental data of the test without flanges seems very reliable, but the measurements that have been done with the flanges seems to be not so "ideal": it has been reported that during this test, the cylinder lose contact in some regions of the supports, introducing a non constant load distribution. In this case, the modeling of boundary conditions can't be realistic and the identificated properties of the flange material seems to be underestimated.

In order to even more confirm the sandwich bending stiffnesses, a refined FE model of the honey comb / skins structure has been created. This model contains all the geometric details of the sandwich panel and the estimated material properties are used for the skins ((0,60,-60) laminate) and the cell walls ((+/-45°) laminate). The simulation results of a pure bending problem are in good agreement with those obtained with the identified sandwich properties, which proves that these values are reliable. This also shows that the estimated values where overestimated because of the linear displacement field assumption of the FSDT homogenization technique. It seems that in high performance sandwiches , this assumption leeds to an overall overestimated stiffness of the laminate, which are usually well estimated for more conventional composites. Some results of this study are shown below:

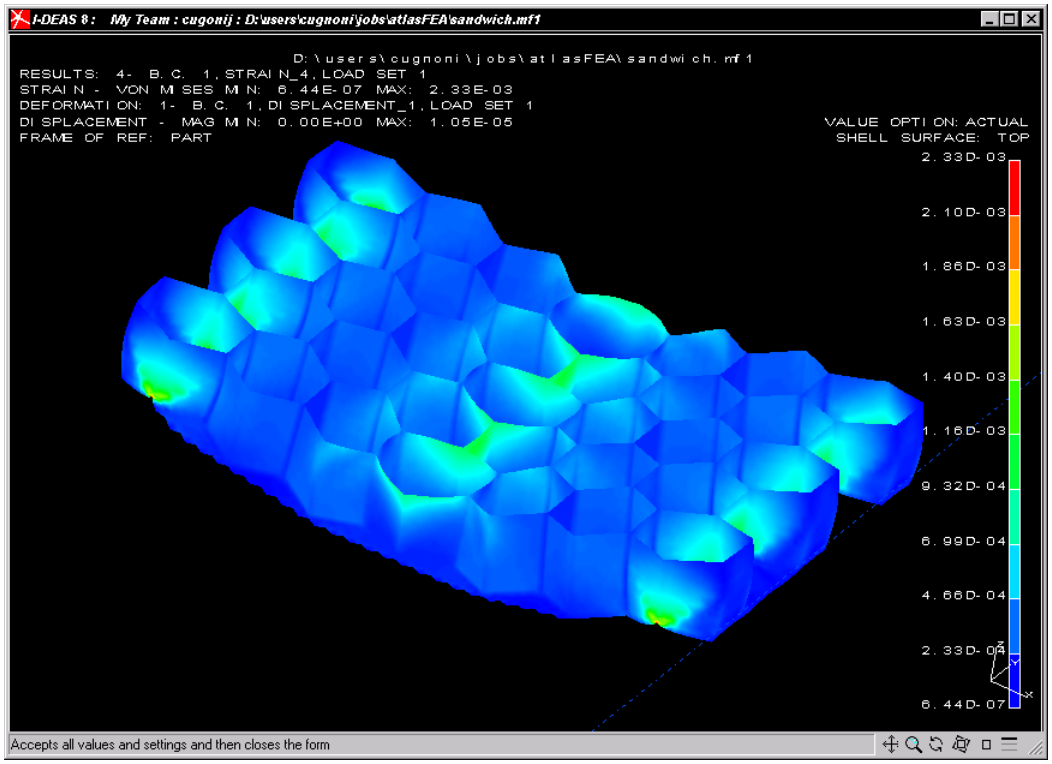


Figure: Illsutration of one half of the refined sandwich FE model.

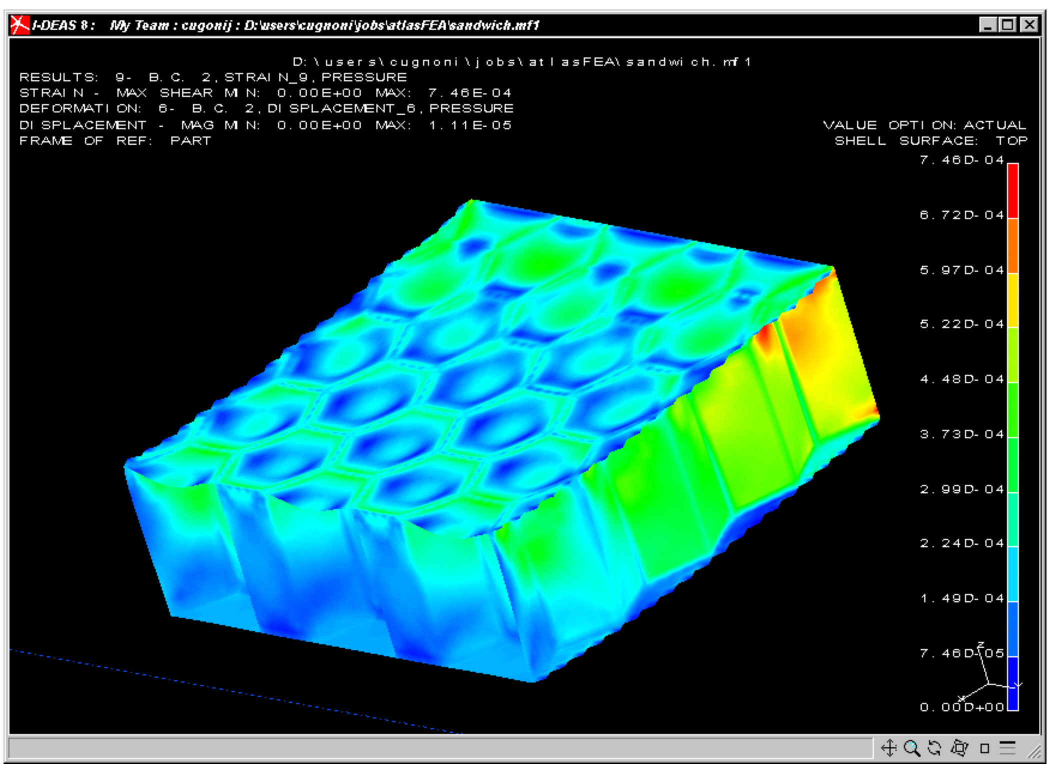


Figure: Strain field in one half of the refined sandwich model under a distributed vertical load

/

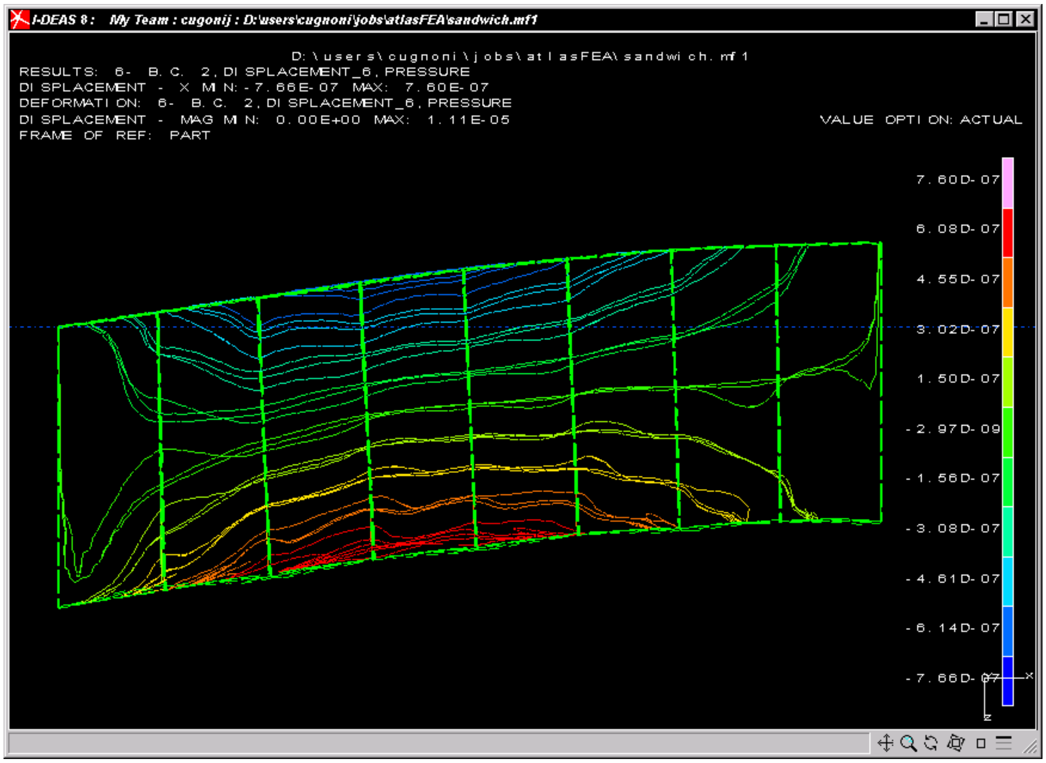
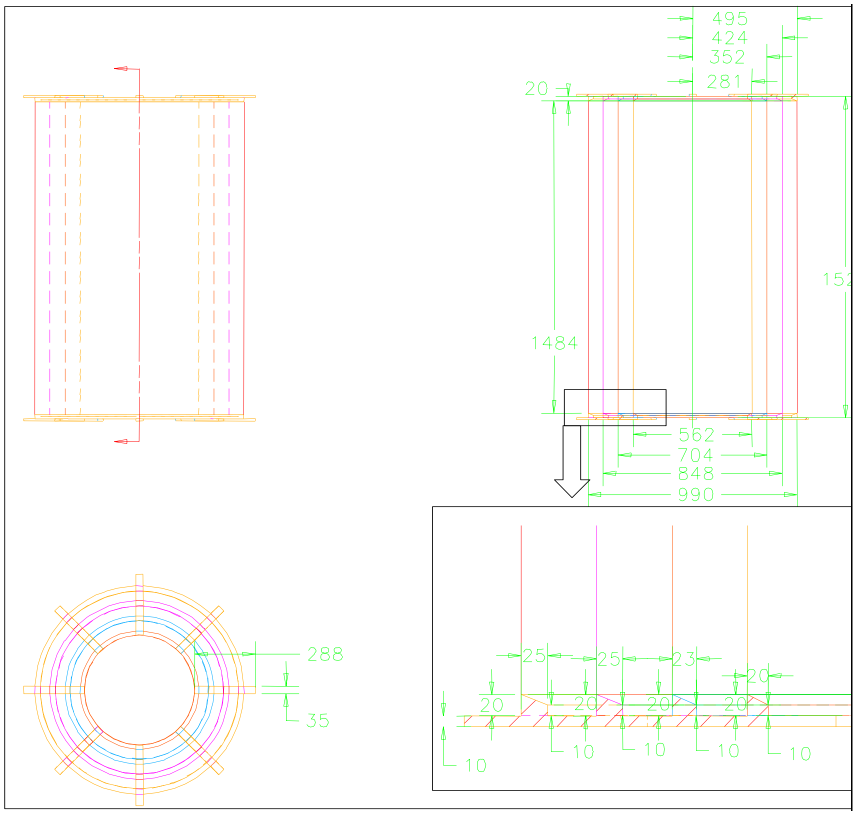
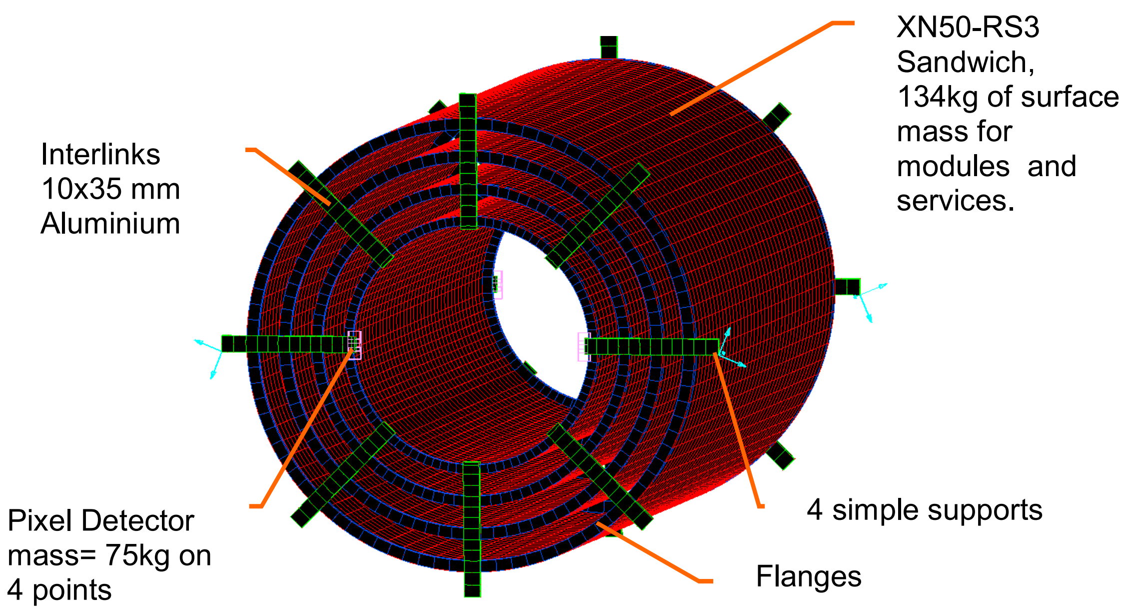


Figure : X (horizontal) displacement field in the refined sandwich model

/

Global ATLAS SCT FE Model





/

The ATLAS SCT assembly has been modeled by FE method. The geometry of the parts, the assembly specifications and the physical properties have been taken from Atlas SCT specification document and from plans (University of Geneva). Here are the different parts of the assembly and their corresponding data :

1. **SCT Barrels:**
   - Material: XN50/RS3 Honey Comb Sandwich , material properties from the numerical / experimental identification. Material modeled as a Laminate. (Appendix 4)
   - Finite Element Formulation: Serendipian (8 nodes) quadratic FSDT shells (Mindlin formulation, 6 DOF per nodes).
   - Typical element size of about 35 mm.
   - Additional mass for services and modules: 134 kg (total), or 9.04 kg/m^2.
   - First principal material direction oriented along the cylinder axis (Z).
   - Perfectly bounded to flanges in the contact regions.
2. **Flanges:**
   - Material: flanges material properties from the homogenization process , Material modeled as an orthotropic elastic material.. (Appendix 4)
   - Finite Element Formulation: Serendipian (8 nodes) quadratic FSDT shells (Mindlin formulation, 6 DOF per nodes).
   - Typical element size of about 35 mm.
   - No Additional mass, only flange's own weight.
   - First principal material direction oriented along the cylinder circumference .
   - Perfectly bounded to cylinders and interlinks in the contact regions.
3. **Interlinks:**
   - Material / Geometry: because the specifications of interlinks are not already determined at the present time, the interlinks have been modeled as 35x10mm beam in standard aluminum (70Gpa).
   - Finite Element Formulation: 10 nodes quadratic tetrahedrons (3 DOF per nodes).
   - Typical element size of about 35 mm.
   - Aluminum density, no additional mass.
   - First principal material direction oriented along the cylinder circumference .
   - Perfectly bounded to cylinders and interlinks in the contact regions.

The standard boundary conditions of the SCT assembly are the following:

- Simple supports on 4 points at the outer end of the the horizontal interlinks (TRT – SCT supports). (blocked translational DOF, free rotations)
- Supports for Pixel Detector: 4 points at the inner end of the horizontal interlinks. Pixel Detector is modeled by 4 concentrated masses at these support points. Total Pixel Detector weight is estimated to be 75kg in this model.
- Gravity field of 9.81 m/s^2.

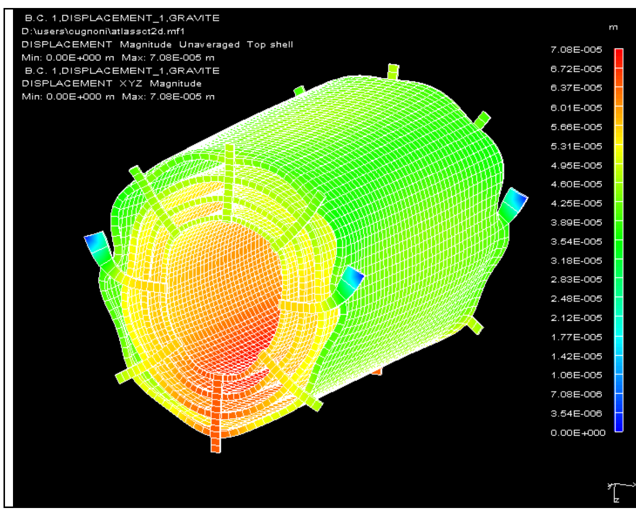
The software used for the FEM modeling and solution is SDRC I-Deas Master v8 (Simulation Module). Some calculations have been done for comparison with Abaqus Standard, and as no significant differences where found between the two solvers, we have exclusively used the "I-Deas Model Solution" solver.

Study of the initial design of SCT Assembly

The aim of this study is to understand the deformation modes of the SCT assembly in its original configuration, in order to guide us in the future structural optimization study The following conditions are used:

1. **Simulation of SCT without Pixel Detector:**
   - Gravity
   - Distributed mass for Modules and Services
   - Structural Weight.
   - 4 simple supports.
2. **Simulation of SCT with Pixel Detector:**
   - Gravity
   - Distributed mass for Modules and Services
   - Concentrated masses representing the weight of the Pixel Detector.
   - Structural Weight.
   - 4 simple supports.

The resulting displacement fields are shown in the four following figures:



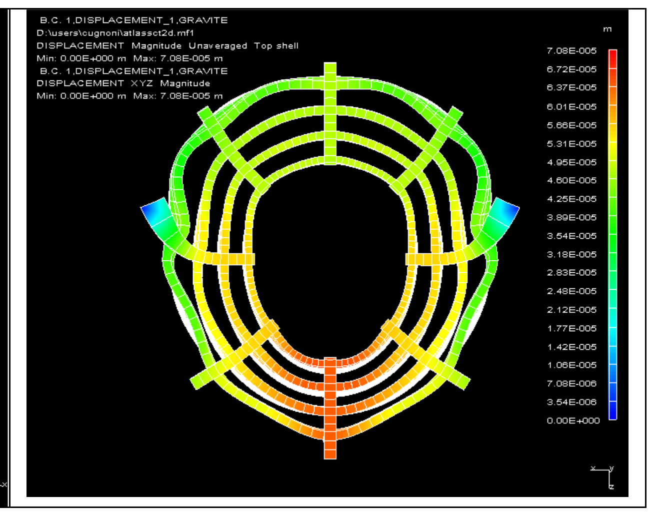


Figure: displacements without Pixel Detector, max = 70 µm

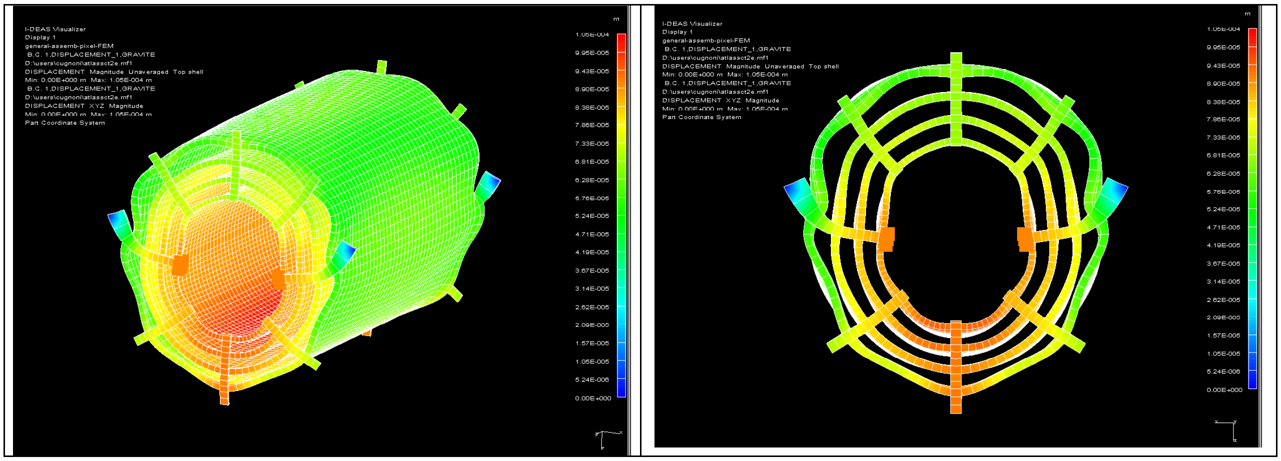


Figure: displacements with Pixel Detector, max = 105 μm

Stiffness optimization study of the SCT Assembly

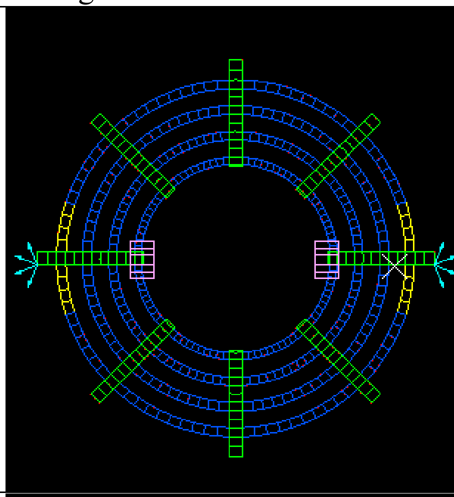
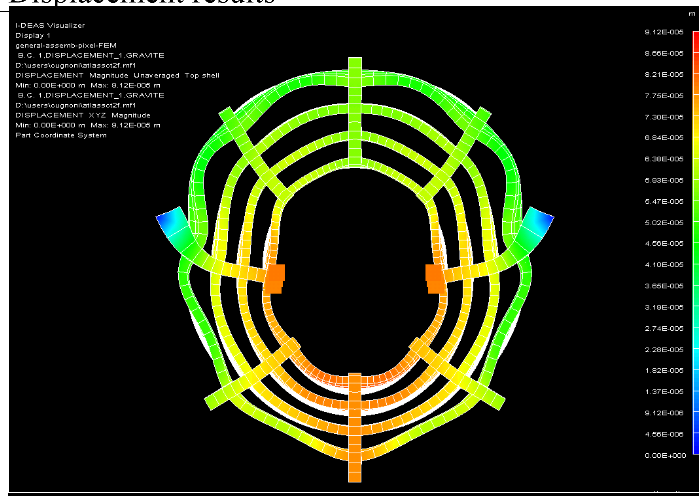
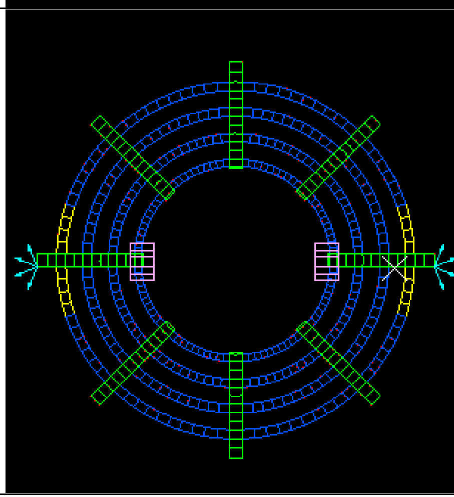
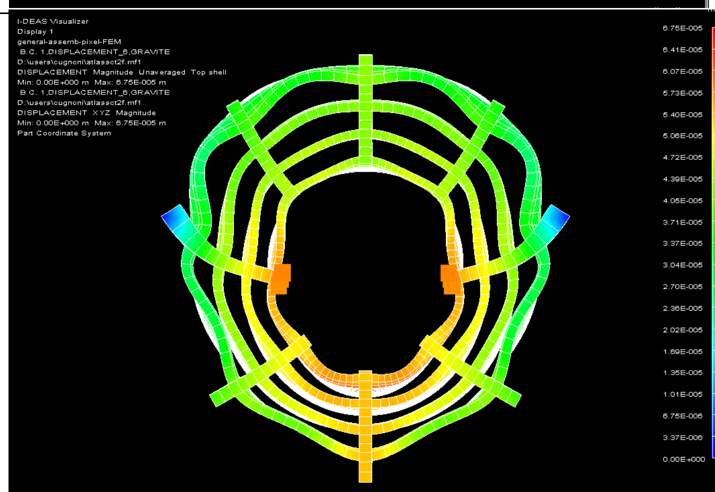
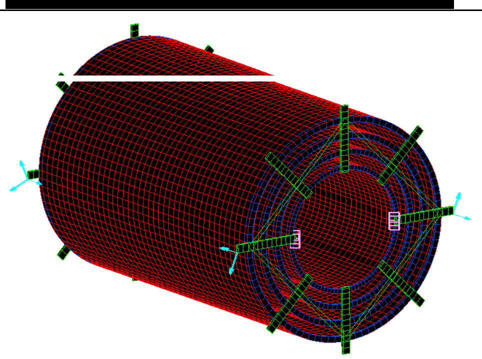
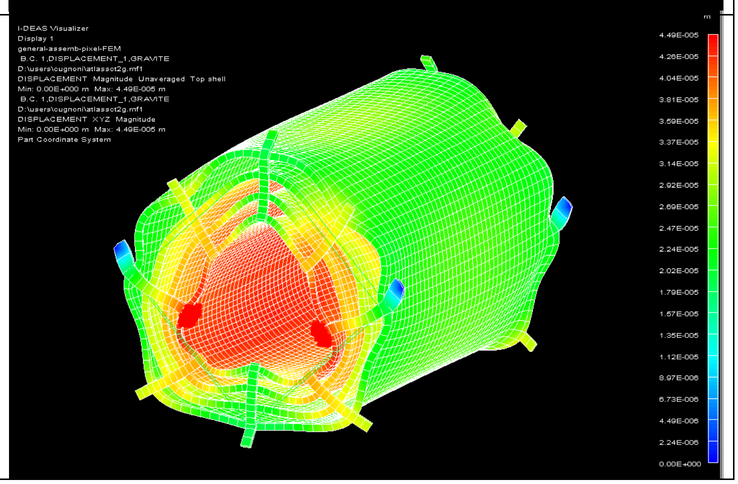
The aim of this study is to analyze the influence of different stiffening methods and to define the optimal method for the reinforcement of the assembly. Different external stiffening methods have been tested, such as infinitely rigid stays (in traction / compression) or external stiffening beams (traction , compression, shear and bending). The effects of the reinforcement of the flanges of barrel 6 or of the stiffness of the interlinks have also been analysed.
All these models use the same material properties and mesh than the preceding ones. The boundary condition are the following (all with Pixel detector included):

- Gravity
- Distributed mass for Modules and Services (134 kg)
- Concentrated masses for Pixel Detector.(75 kg)
- Structural Weight.
- Assembly on 4 simple supports .

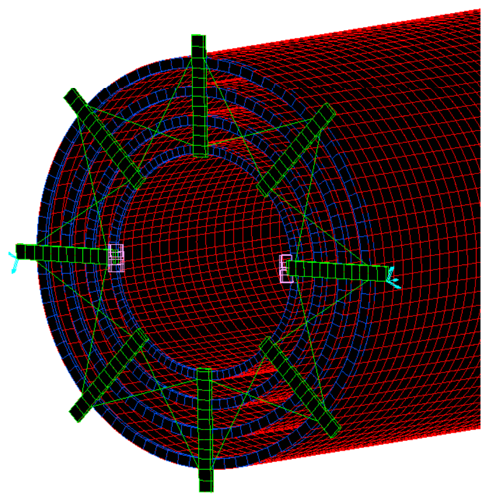
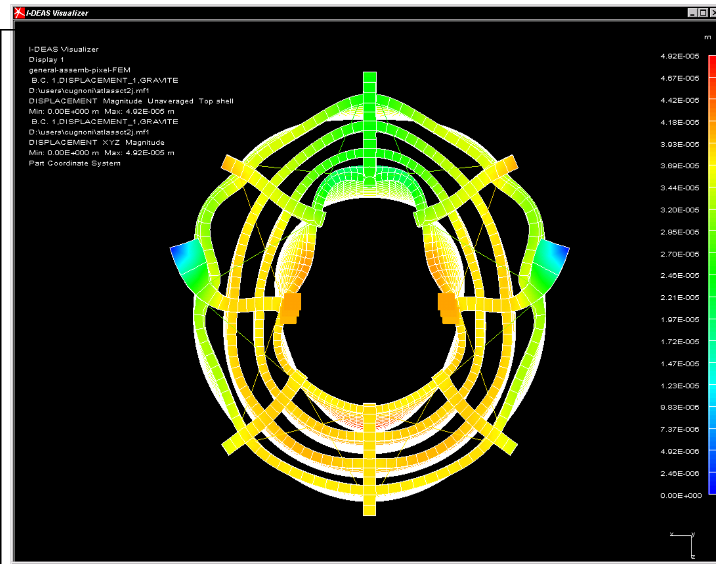
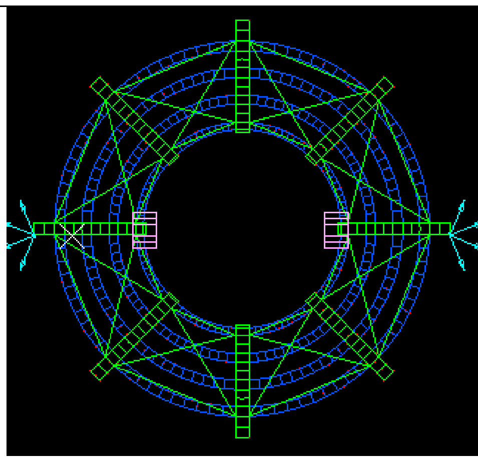
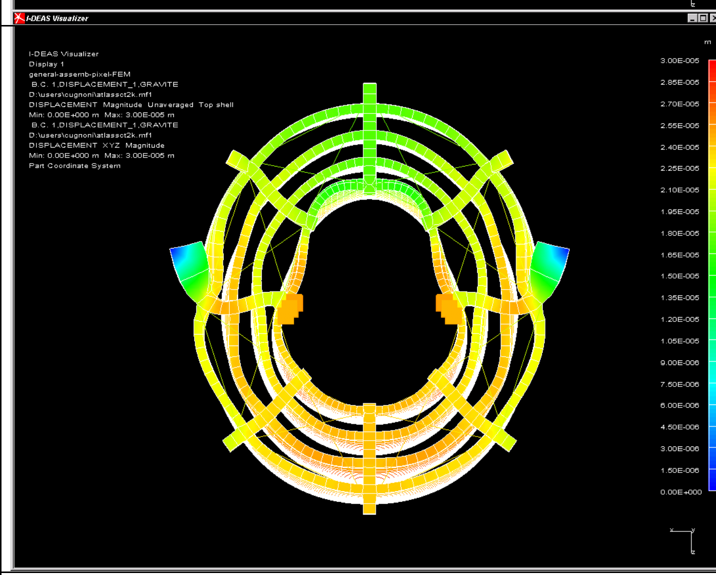
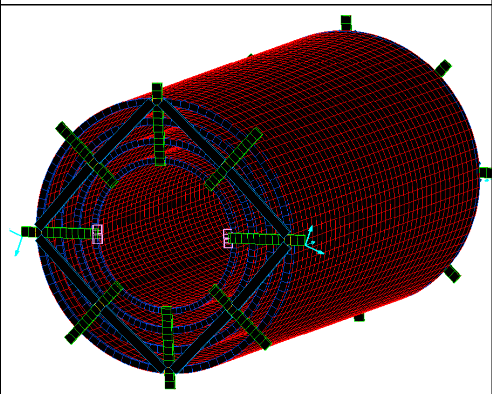
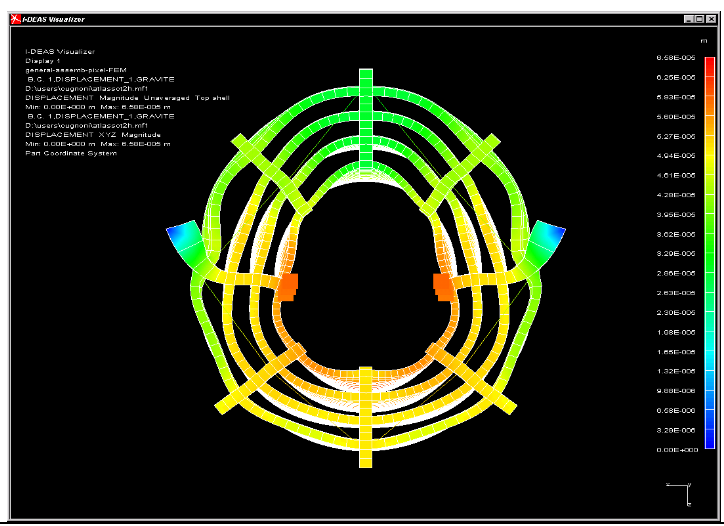
The following stiffening techniques have been investigated :

Case	*Stiffening technique*	Maximum Displacement (mm)
1	Barrel 6 Flange Reinforcement	9.12E-02
2	Barrel 6 Flange Reinforcement + Interlink stiffening	6.75E-02
3	Rigid Stays on 4 points	4.49E-02
4	Crossed Rigid Stays	4.92E-02
5	Closed Loop Rigid Stay Design	3.00E-02
6	Reinforcement Elastic Beams	6.50E-02

Simulation Results:

<table>
<tr><th>#</th><th>Configuration</th><th>Displacement results</th></tr>
<tr><td>1</td><td></td><td>
</td></tr>
<tr><td>2</td><td></td><td>
</td></tr>
<tr><td>3</td><td></td><td>
</td></tr>
</table>

/

<table>
<tr><td>4</td><td></td><td>
</td></tr>
<tr><td>5</td><td></td><td>
</td></tr>
<tr><td>6</td><td></td><td>
</td></tr>
</table>

/

The first conclusion that we can draw, is that it is difficult to stiffen the structure by using stays without having a lot of local deformation of the cylinders, which can be a problem in practical situations. The simulated stays are considered to be infinitely rigid, a corresponding stiffness could not be reached with real stay, even with large cross sections. The external beam can be a good solution, but the space required by these 35x10mm beams could not be free. As a lot of the displacement is induced by the local deformation and rotation of the interlinks between supports and Barrel 6, a good and applicable solution would be to reinforce the B6 Flanges as well as the outer end of the interlinks.

Torsional Behavior of SCT (3 point support)

The aim of this simulation is to predict the maximum deflection of the SCT assembly in the case of a temporary 3 point support (loss of contact of 1 support). The model include the Pixel detector's mass and is essentially the same the standard model : only the boundary conditions have changed from 4 point supports to 3 point support only.

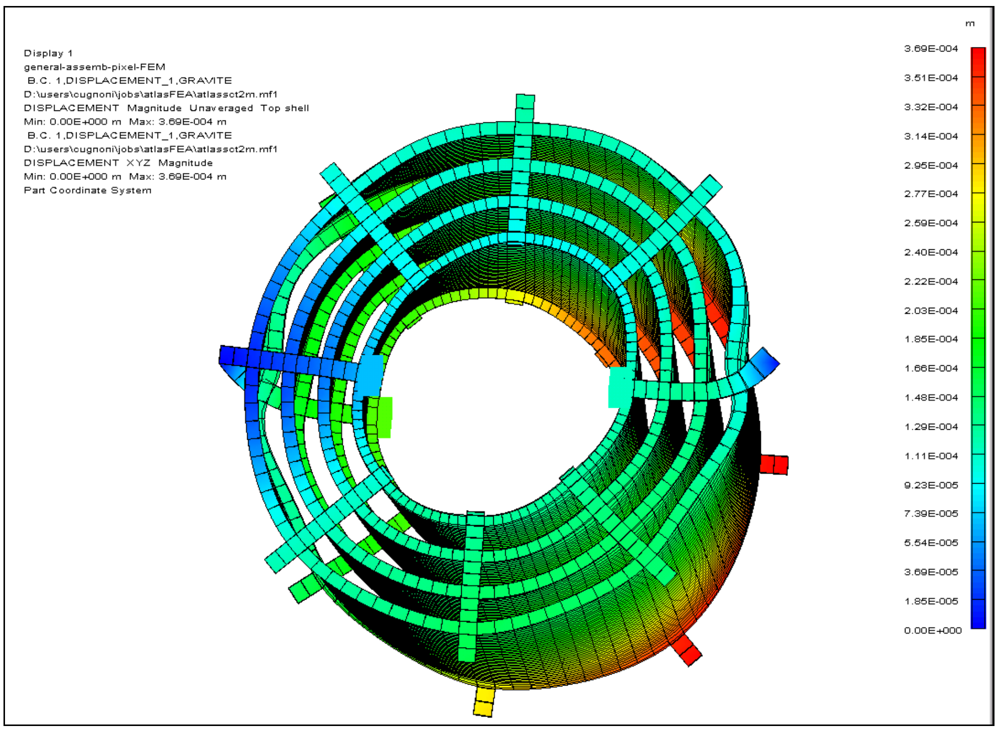


Figure: Deformation of SCT Assembly with temporary 3 point supports. Maximal Deflection (free end of the interlink): 369 microns.

Eigen frequencies of the SCT + Pixel Assembly.

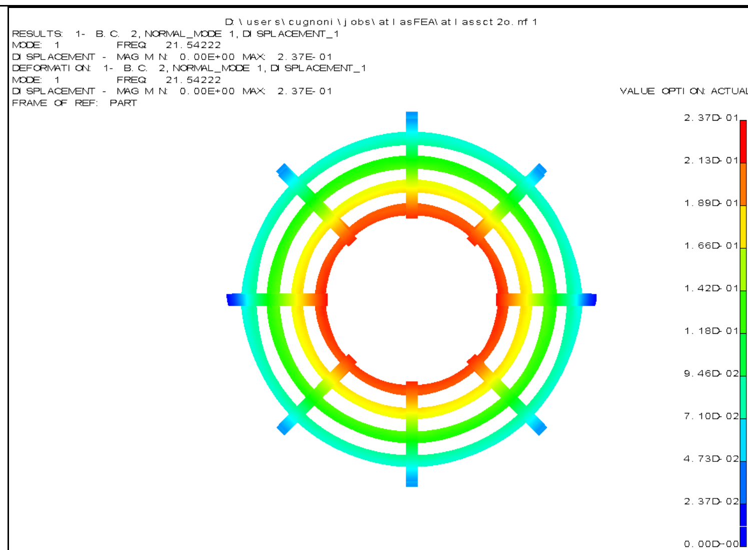
A numerical modal analysis has been carried out in order to estimate the eigen frequencies and eigen modes of the SCT + Pixel assembly. The numerical model is the standard one, which corresponds to the initial design (no reinforcement of the assembly).

Mode	*Eigen Frequencies*
1	21.5 Hz
2	54.4 Hz
3	59.1 Hz
4	60.1 Hz
5	61.9 Hz

The corresponding eigen modes are shown below (amplitude range is unitless, as no excitation is defined):

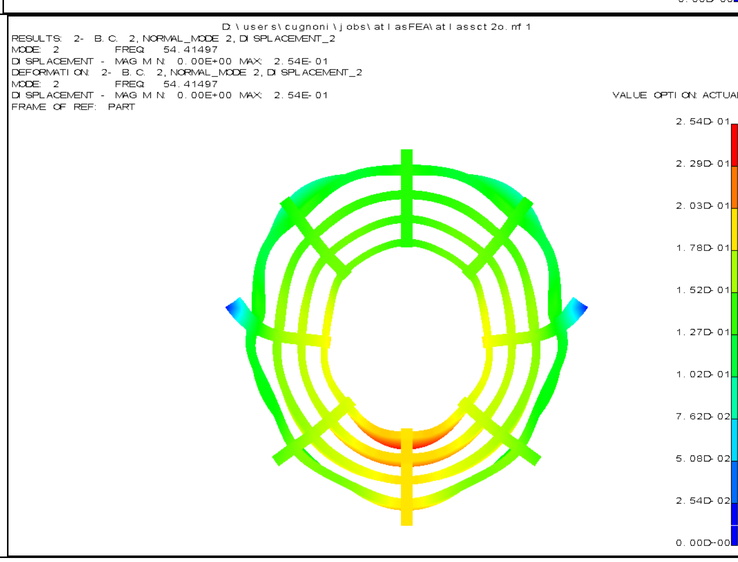
Mode 1:

21.5 Hz

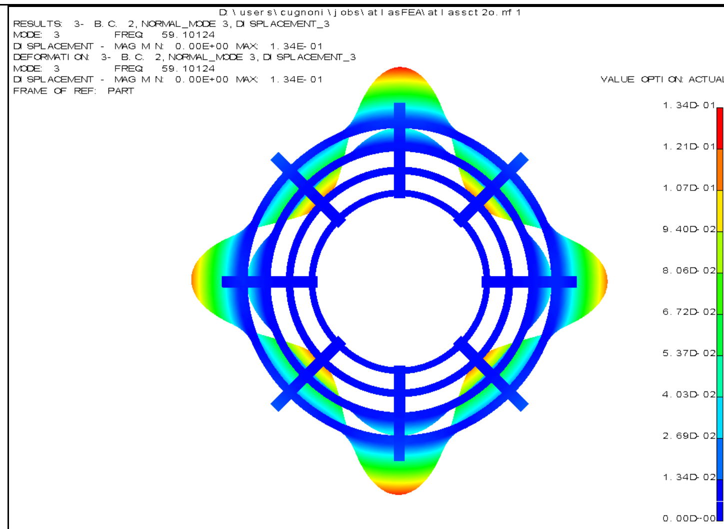
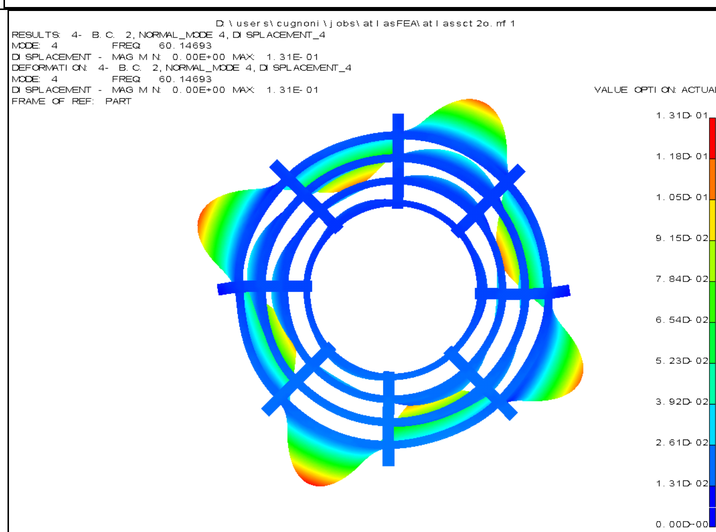
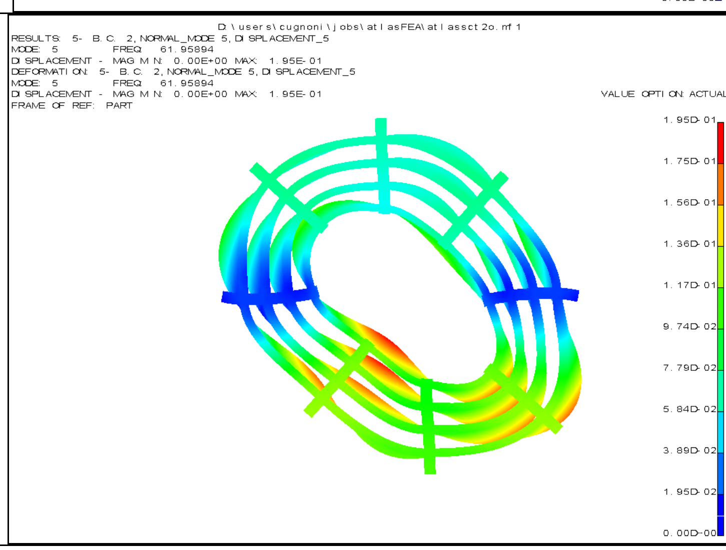


Mode 2:

54.4 Hz



/

Mode 3: 59.1 Hz			
Mode 4: 60.1 Hz			
Mode 5: 61.9 Hz			

/

B6 Flanges and Interlink Reinforcements Study

Following the conclusions of the initial SCT assembly study, we have decided to add a reinforcement to the “B6 flanges to Interlink junction”. This reinforcement part has been added to the SCT assembly FE model. This structure has been modeled using a coarse mesh as we are mainly interested in understanding the global deformations modes of the SCT Assembly. The reinforcement part is approximately 105mm long and is made of quasi isotropicXN50-RS3 laminate (2 mm thickness).

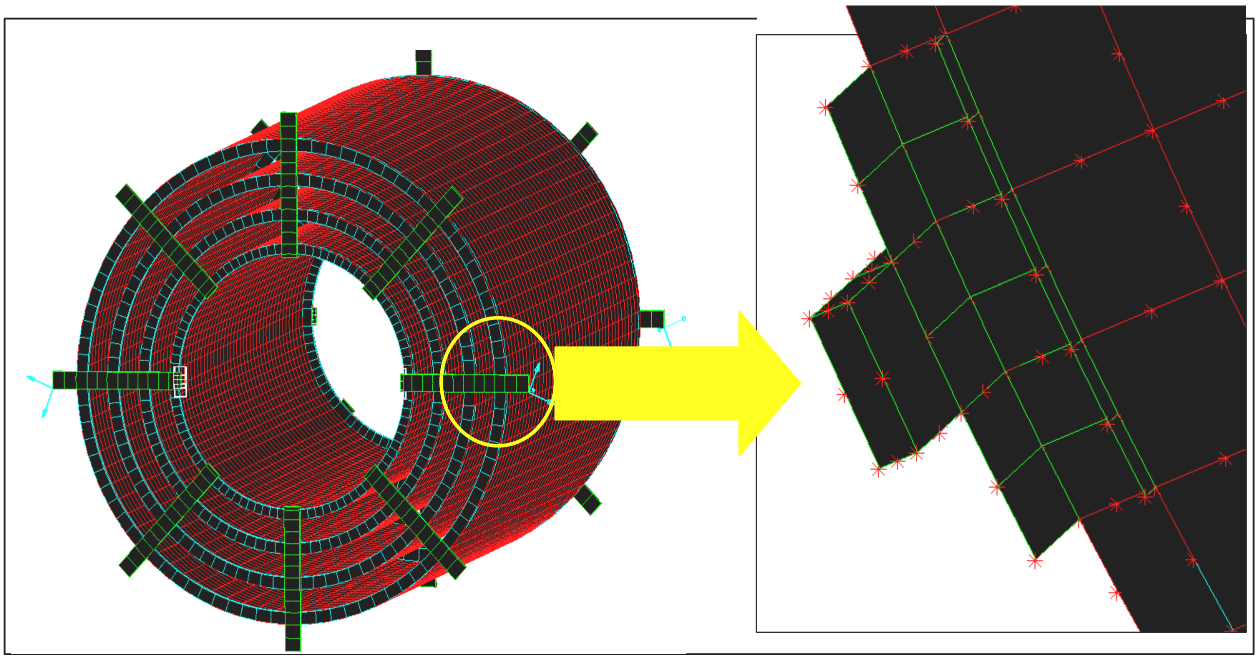
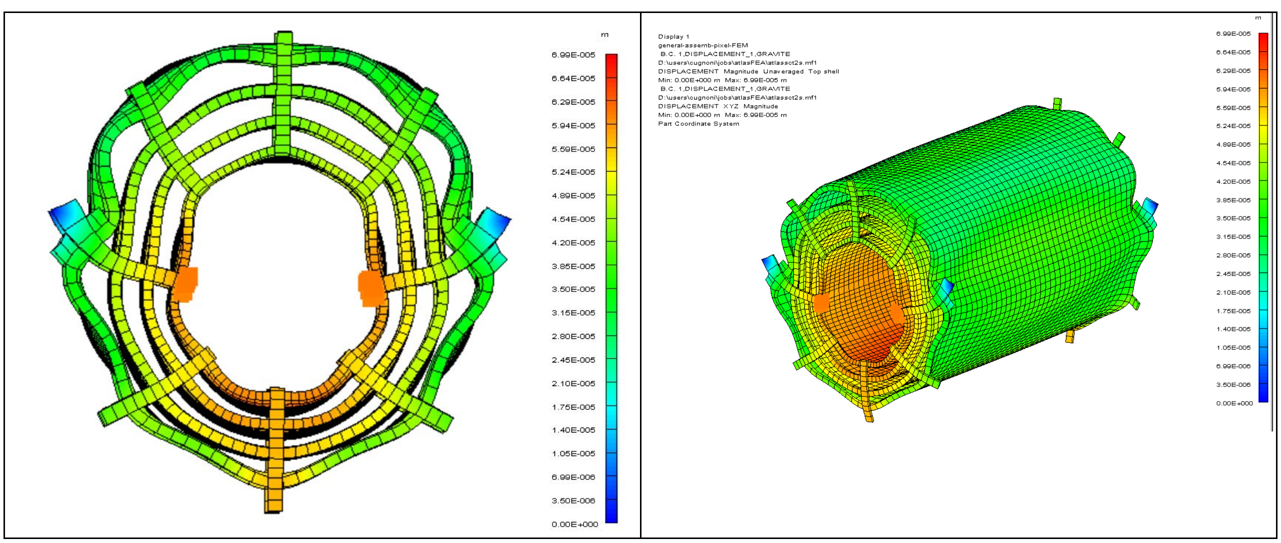


Figure: Barrel 6 flanges to interlinks junction reinforcement part and its FE mesh.

Computation of the displacements of SCT assembly + Pixel (mass) under gravity **with B6 reinforcement part : Maximum deflection of SCT = 69.9 microns.**



/

Comparison of max SCT + Pixel displacement for different stiffening techniques:

Case	Stiffening technique	Maximum Displacement (mm)
0	*Original Design, No reinforcement*	1.05E-01
1	Barrel 6 Flange Reinforcement	9.12E-02
2	Barrel 6 Flange Reinforcement + Interlink stiffening	6.75E-02
3	Rigid Stays on 4 points	4.49E-02
4	Crossed Rigid Stays	4.92E-02
5	Closed Loop Rigid Stay Design	3.00E-02
6	Reinforcement Elastic Beams	6.50E-02
7	B6-interlinks reinforcement part	6.99E-02

Study of the mechanical effects induced by Pixel Insertion

During the Pixel Detector insertion process, it may be possible that a load could act directly from the end of the pixel insertion tube, thus inducing a global bending of the SCT. This study aims to predict the behavior of the SCT assembly in this case of accidental loading. The pixel insertion tubes and pixel inner tube have been modeled as infinitely rigid beams, so this simulation does not account for pixel tubes deformations. In this case, a 200 N load is applied at the end of the pixel insertion tube (supposed free). This case has been solved without gravity, so the deformation shown in this section represent only the effects of the external load.

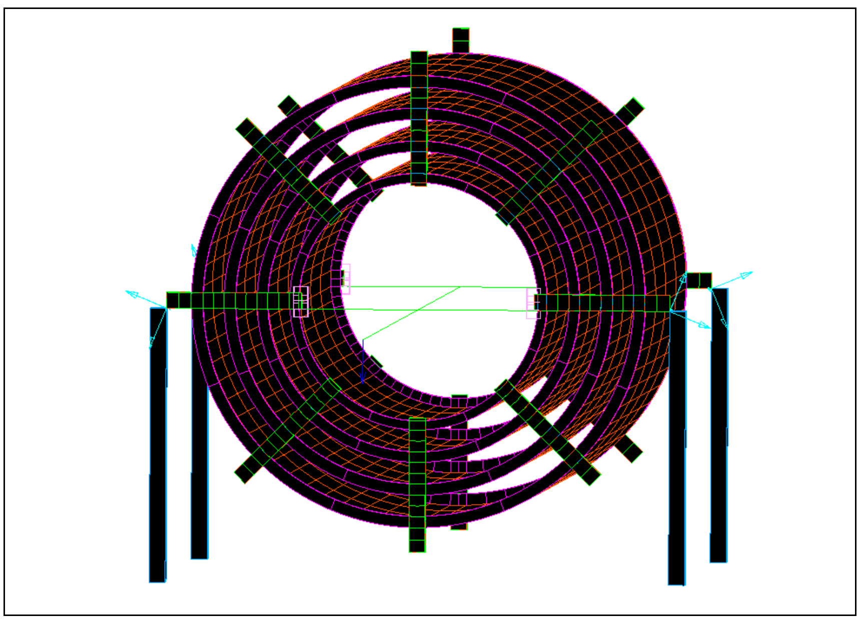


Figure: Finite Element Mesh of SCT + Pixel tubes with external load at the end of Pixel Insertion Tube.

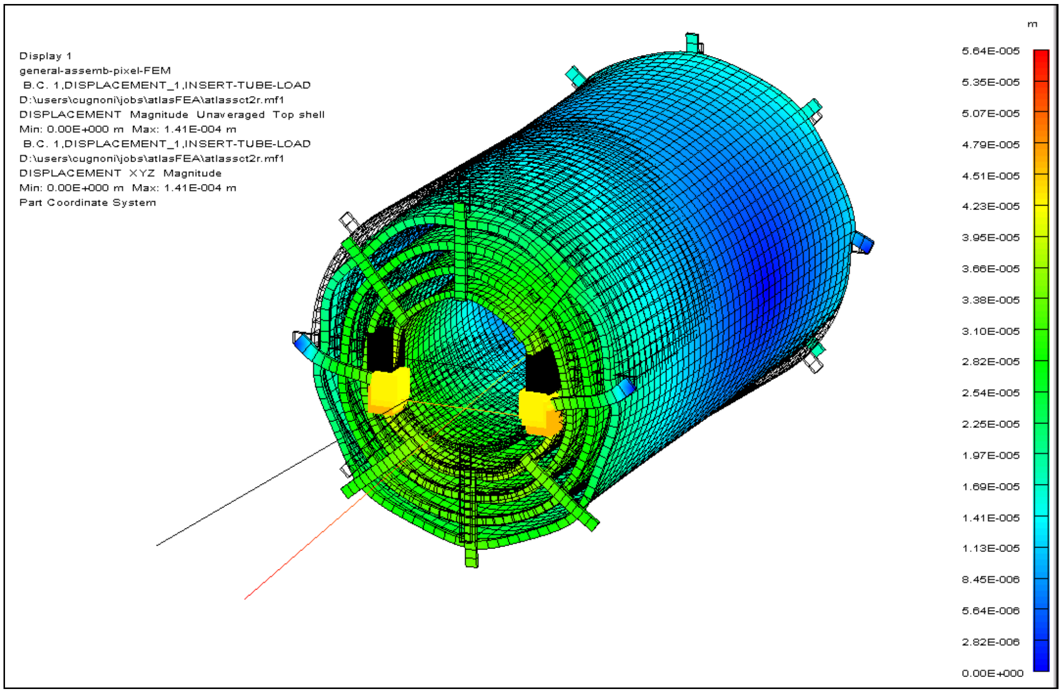


Figure: Deformation mode of the SCT assembly due to an external load at the end of the pixel detector insertion tube.

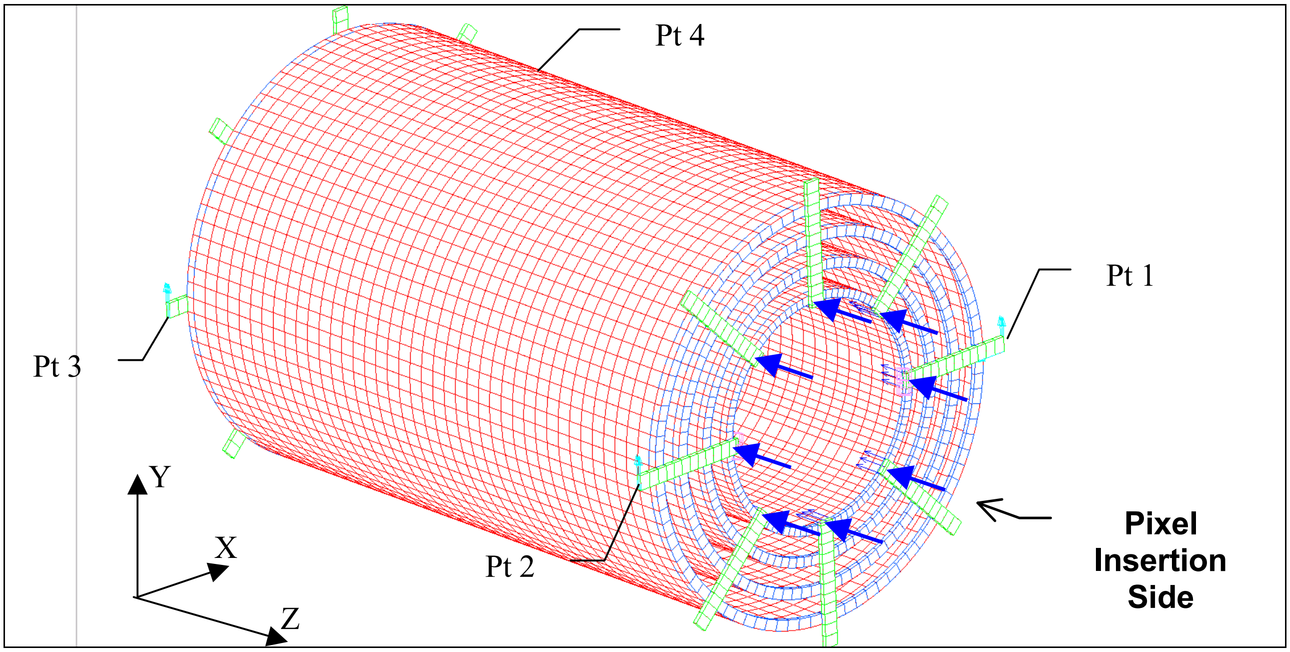
Maximum deflection of the end the insertion tube	***141 microns***
Maximum deflection of SCT structure	***48 microns***

Z stiffness of SCT Assembly

We have also calculated the axial (Z axis) stiffness of the SCT assembly. The boundary conditions that have been used are the following:

Point	***Blocked Translational DOF***	***Free Translational DOF***
1	X,Y,Z	
2	Y	X,Z
3	Y	X,Z
4	X,Y	Z

The assembly is loaded in **8 points** with a total axial (Z) load of **200 N.**



The computed displacements are the following:

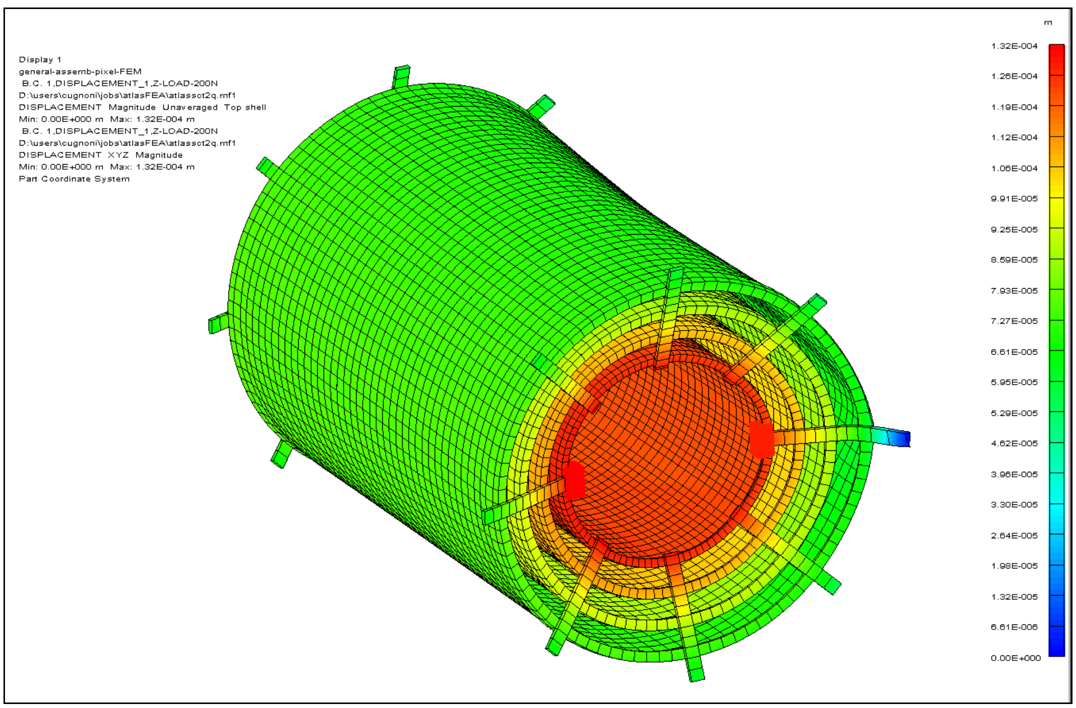


Figure: Displacements induced by a total Z load of 200 N. View form Pixel insertion side.

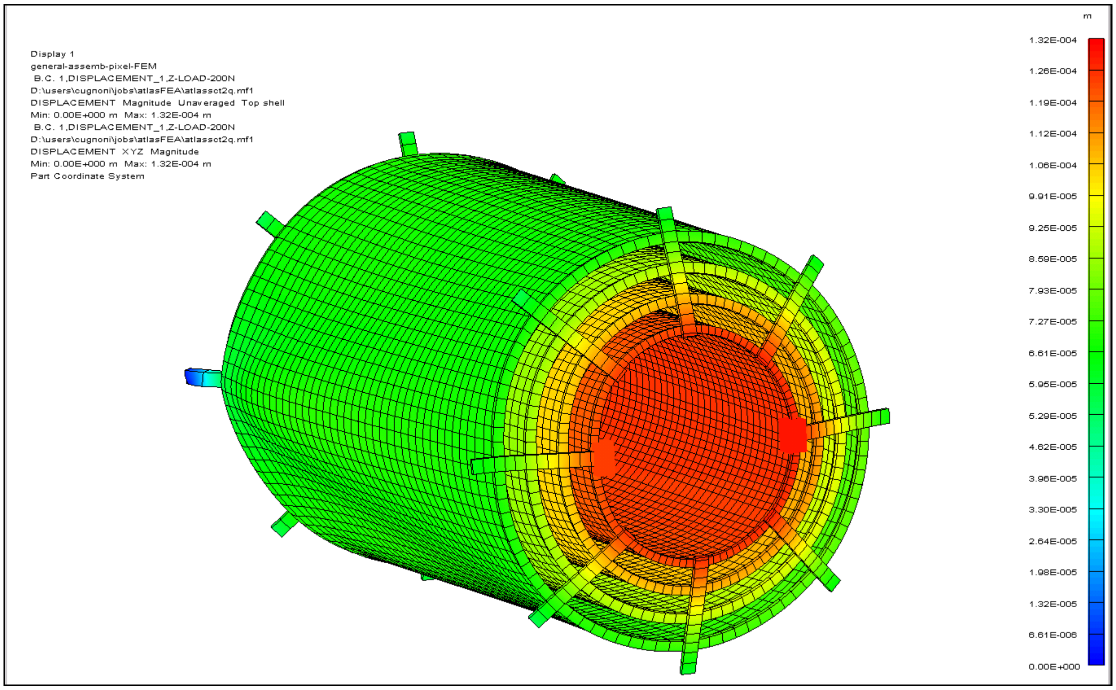


Figure : Displacements, view from the other side.

Axial (Z) apparent stiffness :
Max. Z displacement = 1.32E-04 m
Load = 200 N distributed on 8 points
Equivalent Z stiffness = 1.52E+06 N/m

Other Studies:

The following studies are currently in progress :

- Pixel / SCT stiffness coupling study
- Effects of other TRT / SCT interface types
- Displacements during the SCT Assembly Process.

Appendix:

Appendix 1. XN50 Fibers and RS3 Resin Properties

RS3 resin only
source YLAINC Web: http://www.ylainc.com/products/data_sheets/rs_3.htm,

RS-3 Neat Resin Physical Properties

Property	Value
Density	1.193 g/cm^3
T_g (dry*, wet**)	490° F, 480° F
Coefficient of Thermal Expansion	24 ppm/° F
Outgassing (TML, CVCM)	0.22 %, 0.01 %
Equilibrium Moisture Absorption**	0.69%
Viscosity @ 149° C	21,400 cps
@ 167° C	4,300 cps
@ 185° C	1,450 cps
@ 203° C	595 cps
@ 221° C	270 cps

** Casting cured 2 hours at 350° F and postcured 2 hours at 450° F.*
*** Wet properties determined after specimens exposed to 95% R.H. at 160° F for 20 days.*

RS-3 Neat Resin Mechanical Properties

Property	Value
Tensile Strength	11.6 ksi
Tensile Modulus	430 ksi
Tensile Strain	4.90%
Flexural Strength	18.4 ksi
Flexural Modulus	481 ksi
Fracture Toughness, G_{1c}	2.10 in-lb/in^2

6.54E+09 pa

KSI=1E3 PSI

RS-3 Neat Resin Electrical Properties

Property	Value
Dielectric Constant @ 2-18 GHz	2.67
Loss Tangent	0.005

XN 50A 20N Fibers (Nippon Graphite Fiber Corp.)

Tensile Strength	Tens Modulus	Density	Mass per Length	Size Content	Surf Treatement
MPA	GPA	g/cm3	g/Km	Wt%	
3805	510	2.14	304	1.4	YES

Appendix 2. Fiber / Matrix homogenization of a 60% fiber vol. XN50/RS3 UD lamina

HOMOGENEISATION D'UN COMPOSITE A FIBRE LONGUE UNI DIRECTIONNEL A MATRICE DUCTILE

=Désigne les valeurs à entrer

Caractérisation de la matrice (modèle isotrope)

Variable	Module Your	Coef Poissor	Mod. Cisaillm
Nom	E_m	Nu_m	G_m
Unité	Pa	-	Pa
Valeur	6.54E+09	0.4	2.34E+09

Caractérisation des fibres longues (isotrope modélisé en transotrope)

Variable	Module Young Longitudinal	Module Young Longitudinal	Module Young Transverse	Coef Poisson isotrope	Coef Poisson Long-Trans	Coef Poisson Trans-Trans
Nom	E_f	E_fl	E_ft	Nu_f	Nu_flt	Nu_ftt
Unité	Pa	Pa	Pa	-	-	-
Valeur	5.10E+11	5.10E+11	5.10E+11	0.35	0.35	0.35

Variable	Mod. Cisaillmt isotrope	Mod. Cisaillmt longitudinal	Mod. Cisaillmt tranverse
Nom	G_f	G_fl	G_ft
Unité	Pa	Pa	Pa
Valeur	1.89E+11	1.96E+11	1.96E+11

Caractérisation du composite

Variable	Volume relatif de fibre	Volume relatif de matrice
Nom	V_f	V_m
Unité	% vol tot	% vol tot
Valeur	60%	40%

Composite (modèle transverse-isotrope):

Valeurs Proposées:

Variable	Module Young Longitudinal	Module Young Transverse	Module Cisail Longitudinal	Module Cisail Transverse	Coef Poisson Long-Transv	Coef Poisson Transv-Transv	Coef Poisson Transv-Long
Nom	E_cl	E_ct	G_cl	G_ct	Nu_clt	Nu_ctt	Nu_ctl
Unité	Pa	Pa	Pa	Pa	-	-	-
Valeur	3.086E+11	1.892E+10	8.928E+09	8.034E+09	0.369	0.602	0.026

Density

Matrix	Fibers	%vol fibre	Density
1.19	2.14	60%	1.76

Models from Abolinsh and Vanyin (Van Fo Fy), source Bogdanovich, Pastor, Mechanics of Textile and Laminated composites, London: Chapman & Hall, 1996, ref BC: Jd 754.

Appendix 3. Flanges Material Homogenization

FLASQUES EN XN50RS3 ou equiv

1ere modlisation:
flasques en XN50RS3 quasi isotrope de 2mm d'épais en 8 couches (0,45,90,-45)s

Propriétés du laminé homogénéisé

Comportement en membrane

Aij	1 (1)	2 (2)	3 (6)
1 (1)	2.60E+08	8.42E+07	0.00E+00
2 (2)	8.42E+07	2.60E+08	7.45E-09
3 (6)	0.00E+00	7.45E-09	8.80E+07

Comportement en couplage membrane/flexion

Bij	1 (1)	2 (2)	3 (6)
1 (1)	0.00E+00	0.00E+00	0.00E+00
2 (2)	0.00E+00	0.00E+00	0.00E+00
3 (6)	0.00E+00	0.00E+00	0.00E+00

Comportement en flexion

Dij	1 (1)	2 (2)	3 (6)
1 (1)	1.41E+02	1.93E+01	1.37E+01
2 (2)	1.93E+01	4.98E+01	1.37E+01
3 (6)	1.37E+01	1.37E+01	2.06E+01

Comportement en cisaillement transverse (sans correction)

Dij	1 (4)	2 (5)
1 (1)	1.70E+07	2.91E-11
2 (2)	2.91E-11	1.70E+07

Matériau orthotrope équivalent (pour laminés symmétriques uniquement, en ignorant les couplages!!!)

Variable	Module de Young E1	Module de Young E2	Coef Poisson Nu12	Coef Poisson Nu21	Module de Cisaillement 12	Module de Cisaillement 23	Module de Cisaillement 31
Unité	Pa	Pa	-	-	Pa	Pa	Pa
Valeur	1.16E+11	1.16E+11	3.24E-01	3.24E-01	4.40E+10	8.48E+09	8.48E+09

Appendix 4. Atlas SCT Assembly : Material properties.

Matériaux

SANDWICH NID-D'ABEILLE XN50RS3

MODELE : LAMINE
Propriétés du laminé homogénéisé
Note: ces propriétés résultent de l'identification avec le cylindre test CASA. Elles représentent donc des valeurs sous estimées des propriétés réelles.
Epaisseur 5.99E-03 m
Densité 3.03E+02 kg/m3

Comportement en membrane

Aij	1 (1)	2 (2)	3 (6)
1 (1)	6.60E+07	2.43E+07	0.00E+00
2 (2)	2.43E+07	6.60E+07	0.00E+00
3 (6)	0.00E+00	0.00E+00	2.15E+07

Comportement en couplage membrane/flexion

Bij	1 (1)	2 (2)	3 (6)
1 (1)	0.00E+00	0.00E+00	0.00E+00
2 (2)	0.00E+00	0.00E+00	0.00E+00
3 (6)	0.00E+00	0.00E+00	0.00E+00

Comportement en flexion

Dij	1 (1)	2 (2)	3 (6)
1 (1)	1.31E+02	4.84E+01	0.00E+00
2 (2)	4.84E+01	1.31E+02	0.00E+00
3 (6)	0.00E+00	0.00E+00	4.28E+01

Comportement en cisaillement transverse (sans correction)

Dij	1 (4)	2 (5)
1 (1)	1.52E+07	0.00E+00
2 (2)	0.00E+00	3.85E+06

FLASQUES
Matériau orthotrope équivalent

Variable	Module de Young E1	Module de Young E2	Coef Poisson Nu12	Coef Poisson Nu21	Module de Cisaillement 12	Module de Cisaillement 23
Unité	Pa	Pa	-	-	Pa	Pa
Valeur	1.16E+11	1.16E+11	3.24E-01	3.24E-01	4.40E+10	8.48E+09

Module de Cisaillement 31
Pa
8.48E+09